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Final Report: 0078508

Final Report for Period: 09/2000 - 08/2003

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Principal Investigator: Mori, Warren B.

Award ID: 0078508

Organization: U of Cal Los Angeles

Title:

Continuation of Full-Scale Three-Dimensional Numerical Experiments on High-Intensity Particle and Laser Beam-Matter Interactions

Project Participants

Senior Personnel

Name: Mori, Warren

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: decyk, viktor

Worked for more than 160 Hours: Yes

Contribution to Project:

manages parallel code development and works on appleseed cluster

DOE Patent Clearance Granted
MPDvorscak
6-2-04
Date

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Post-doc

Name: dodd, evan

Worked for more than 160 Hours: Yes

Contribution to Project:

Used OSIRIS to carry out full-scale simulations of PWFA experiments and studied electron hosing of GeV beams for realistic beam profiles.

Name: Ren, Chuang

Worked for more than 160 Hours: Yes

Contribution to Project:

Studied 3D wakes from beam drivers and is continuing to develop a wakefield theory for magnetized plasmas. Beginning to study the absorption of ultra-intense lasers on overdense plasma slabs.

Name: Tsung, Frank

Worked for more than 160 Hours: Yes

Contribution to Project:

Maintains the code osiris and studies how short pulses evolve while propagating through underdense plasmas. Modeling self-modulated wakefield experiments in three-dimensions.

Graduate Student

Name: Wang, Shoquin

Worked for more than 160 Hours: No

Contribution to Project:

Studied spontaneous x-ray radiation from betatron motion when an intense electron beam self-consistently forms an ion channel.

Name: Tonge, John

Worked for more than 160 Hours: No

Contribution to Project:

Studied colliding electron-positron clouds.

Name: Huang, Chung-Kun

Worked for more than 160 Hours: No

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Contribution to Project:

Developing a 3D parallel quasi-static PIC code called quickPIC.

Name: Lu, Wei**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Using osiris to model plasma wakefield acceleration. The parameters are of relevance of a future experiment at SLAC.

Name: Fahlan, Jay**Worked for more than 160 Hours:** No**Contribution to Project:**

A beginning student who will model the interaction of an intense laser on a solid.

Name: Winjum, Benjamin**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Used the code OSIRIS to study underdense laser-plasma interactions

Name: Zhou, MiaoMiao**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Used the code quickPIC to study beam-plasma interactions

Name: Tzoufras, Michael**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Used the code OSIRIS to study laser-plasma interactions

Undergraduate Student**Technician, Programmer****Other Participant****Research Experience for Undergraduates****Organizational Partners****Other Collaborators or Contacts**

Tom Katsouleas USC
L.O.Silva IST Portugal
J.C.Adam Ecole Polytechnique
Tom Antonsen, U.Maryland

Activities and Findings**Research and Education Activities:**

Major research activities:

1. Continued development of the full 3D parallel PIC code OSIRIS.
2. Parallel computing using OSIRIS
 - a. Modeled the PWFA experiment e-157.
 - b. Modeling LWFA experiments.

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- c. Modeling SMLWFA experiments.
- d. Modeling positron wakes.
- e. Modeling electron-positron cloud interactions.
- f. Modeling the electron hosing instability.
- h. Modeling overdense laser plasma interactions.
- 3. Developing theoretical models for the mutual interaction of lasers in plasmas.
- 4. Developed a new 3D parallel quasi-static PIC code called quickPIC.
- 5. Developing tools for our appleseed cluster.
- 6. Developing theoretical models for laser-plasma interactions in magnetized plasmas.
- 7. Started to use quickPIC to study
 - a. hosing of electron beams
 - b. positron wakes in uniform and hollow plasmas

Findings:

Major findings:\

Mutual attraction of lasers in plasmas: braided light:
We continued to study the mutual attraction of lasers in plasmas. We showed using a variational principle that there is a profound difference when the nonlinearity is not instantaneous. Furthermore, we found that the lasers can repel when the coherence between the two lasers is taken into account.

Refraction of a particle beam:

We found that when a particle beam leaves a plasma gas interface it bends due an impulse from the collective fields at the plasma edge.

Electron beam hosing:

We have studied the electron hosing of GeV beams. We find that while hosing occurs it is with a lower growth rate than simple theory predicts. Furthermore, we find that when gross hosing occurs it does not necessarily destroy the wake.

Development of quickPIC:

We have developed a new 3D parallelized quasi-static PIC code. Currently the code is tailored for studying the interaction of highly relativistic and narrow particle beam-plasma interactions. The code imbeds a 2D parallel PIC code inside a 3D parallel PIC code.

Positron wakes:

We studied plasma wakefield excitation by positron beams in a regime for which the plasma dynamics are highly nonlinear. We used OSIRIS for this study. In the electron driver case plasma electrons are blown out while in the positron driver case they are pulled in. Although analogous, the two wakefield cases are quite different in terms of their amplitudes, wavelengths, waveforms, transverse profiles, and plasma density dependence. In a homogenous plasma, nonlinear positron wakes are smaller than those of the corresponding electron case. However, hollow channels are shown to enhance the amplitude of the positron wakes.

Self-modulated laser wakefield acceleration:

We studied the SMLFWA of 35 fs laser pulses. We modeled

ongoing experiments in their full scale in 1,2, and 3 dimensions. We found that the number of electrons and the maximum energy of an accelerated electron both decrease as the plasma density is raised. This was consistent with published experimental data. Furthermore, we find that at the highest density ($n/n_c = 1$) that the laser is completely absorbed within 300 μm .

Laser wakefield acceleration in cm long plasma channels:

We performed full scale 3d simulations of LWFA in a channel. We found that short pulse, 50fs, moderately intense laser, $\sim 15\text{TW}$, could be focused into a leaky channel of density $\sim 5 \times 10^{18} \text{cm}^{-3}$ and maintain its intensity for a cm. Furthermore, the laser's intensity evolves due to a combination of photon deceleration and group velocity dispersion so that it eventually leads to self-injection of electrons from the channel walls. These electrons eventually reach .84 GeV energies.

Overdense laser plasma interactions:

We studied that generation of energetic protons when an intense short-pulse laser pulse hits a overdense plasma slab. We found a new acceleration mechanism. Initially electrons are accelerated across the slab. Some leave and others reflect from the back side and return to the front side. At this time an ion acoustic shock is launched that traps and accelerated protons to relativistic energies. This work is being done in collaboration with the group in Portugal.

PWFA simulations:

We are modeling the experimental parameters of a proposed experiment at SLAC called E-164. We find that for these parameters that the wake amplitude that the optimum plasma density is above that predicted from linear theory. Furthermore, we find that a small number of electrons are self-trapped and this number can be much larger due to secondary impact ionization.

Afterburners:

We made preliminary studies of key aspects of the afterburner concept. We found that for these parameters that the hosing instability is greatly suppressed. We also found a beamloading regime where a loaded transformer ratio exceeding 2 is possible.

Training and Development:

Research on this project is training both post-docs and students in the use of massively parallel computing in high-energy density laser and beam plasma interactions.

Outreach Activities:

Our development of an easy to use applesseed cluster continues to have impact to K12 students. In fact, a sixth grader has downloaded our software to network two macintosh computers together. We are continually being contacted by high-schools and universities about how to build an applesseed cluster.

Journal Publications

S.Lee, T.Katsouleas, R.G.Hemker, E.S.Dodd, and W.B.Mori, "Plasma-wakefield acceleration of a positron beam", Phys Rev. E rapid communications, p. 045501, vol. 64, (2001). Published

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Chengkun Huang, Viktor Decyk, Shuoqin Wang, Evan S.Dodd, Chuang Ren, Warren B. Mori, Tom Katsouleas, and Tom Antonsen Jr., "quickPIC: A parallelized quasi-static PIC code for modeling plasma wakefield acceleration", Proceedings of the 2001 Particle accelerator conference, p. 4005, vol. 5, (2001). Published

E.S.Dodd, R.G.Hemker, C-K. Huang, C.Ren, W.B.Mori, S.Lee, and T.Katsouleas, "Hosing and sloshing of short-pulse GeV class wakefield drivers", Physical Review Letters, p. 125001, vol. 88, (2002). Published

Patric Muggli, S.Lee, T.Katsouleas, R.Assman, F.J.Decker, M.Hogan, R.Iverson, P. Raimondi, R.Siemann, D.Walz, B.Blue, C.Clayton, E.Dodd, R.Fonseca, R.Hemker, C.Joshi, K.Marsh, W.Mori, S.Wang, "Collective refraction of a beam of electrons at a plasma-gas interface", Nature, p. 43, vol. 411, (2001). Published

F.S.Tsung, C.Ren, L.O.Silva, R.G.Hemker, W.B.Mori and T.Katsouleas, "Generation of high-intensity single cycle pulses using photon deceleration", Proceedings of the National Academy of Sciences, p. 29, vol. 99, (2002). Published

C.Ren, B.J.Duda, and W.B.Mori, "Braiding of two laser beams due to plasma wakefields", Physical Review E, p. 067401, vol. 64, (2001). Published

Ren C, et al., "On the mutual interaction between laser beams in plasmas", Physics of Plasmas, p. 2354, vol. 9, (2002). Published

Clayton CE et al., "Transverse envelope dynamics of a 28.5-GeV electron beam in a long plasma", Physical Review Letters, p. 154801, vol. 88, (2002). Published

Wang Shuoqin et al., "X-ray emission from betatron motion in a plasma wiggler", Physical Review Letters, p. 135004, vol. 88, (2002). Published

Lee S. et al., "Energy doubler for a linear collider", Physical Review Special Topics-Accelerators and Beams, p. 011001, vol. 5, (2002). Published

Joshi C.et al., "High energy density plasma science with an ultrarelativistic electron beam", Physics of Plasmas, p. 1845, vol. 9, (2002). Published

M. J. Hogan, C. E. Clayton, C. Huang, P. Muggli, S. Wang, B. E. Blue, D. Walz, K. A. Marsh, C. L. O'Connell, S. Lee, R. Iverson, F-J. Decker, P. Raimondi, W. B. Mori, T. C. Katsouleas, C. Joshi and R. H. Siemann, "Ultrarelativistic-Positron-Beam Transport through Meter-Scale Plasmas", Physical Review Letters, p. 205002-1, vol. 90, (2003). Published

B. E. Blue, C. E. Clayton, C. L. O'Connell, F-J. Decker, M.J. Hogan, C. Huang, R. Iverson, C. Joshi, T. C. Katsouleas, W. Lu, K. A. Marsh, W. B. Mori, P. Muggli, R. Siemann, and D. Walz, "Plasma-Wakefield Acceleration of an Intense Positron Beam", Physical Review Letters, p. 214801-1, vol. 90, (2003). Published

C. O'Connell, F-J. Decker, M. J. Hogan, R. Iverson, P. Raimondi, R. H. Siemann, D. Walz, B. Blue, C. E. Clayton, C. Joshi, K. A. Marsh, W. B. Mori, S. Wang, T. Katsouleas, S. Lee, and P. Muggli, "Dynamic focusing of an electron beam through a long plasma", Phys. Rev. Special Topics-Accelerators and Beams, p. 121301-1, vol. 5, (2002). Published

Books or Other One-time Publications

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